1.0

1.1

1.25 1.4 1.6

2.8 2.5

3.2 2.2

3.6

4.0 2.0

1.8

MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963 A

SIDEWALL FORCES ON RICHARD B. RUSSELL FLIP BUCKET SPILLWAY, SAVANNAH RIVER

Hydraulic Model Investigation

by

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Final Report

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

    · The Richard B. Russell flip bucket energy dissipator and the powerhouse tailrace is separated by a concrete wall to reduce lateral flow. The physical hydraulic model investigation was primarily concerned with providing design information relative to the magnitude, frequency, and location of the resultant dynamic loading acting on the flip bucket sidewall located between the powerhouse and spillway for various discharges. Tests were also conducted to determine the upper nappe trajectory for the maximum anticipated spillway discharge

(Continued)

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20. ABSTRACT (Continued).

and the minimum height of flip bucket sidewall required.

Model results indicated that the resultant dynamic forces acting on the sidewall resulted from the combination of turbulence on the flip bucket side of the wall and hydrostatic pressure on the powerhouse side of the wall. It was possible to lower the top of the downstream portion of the sidewall from el 393 to el 356 without return flow passing over the top of the wall. With the top of this wall lower than el 356, return flow over the top of the sidewall contributed to adverse flow conditions including increased current velocities in the powerhouse tailrace, confinement of flow along the left side of the exit channel, and lateral flow entrainment with flow from the flip bucket.

Tests conducted, with and without the wall immersed in water, to investigate the natural frequency and damping of the model wall indicated that the natural frequency of the model wall was too high to influence the results of the tests and there was no discernible damping of the forces due to the mechanical system. Forces on the sidewall were measured for the standard project flood (discharge 360,000 cfs) and the maximum project flood (discharge 800,000 cfs). The data obtained were analyzed and the magnitude and frequency of the resultant force and overturning moment relative to the base of the wall (el 300) were computed and tabulated.

The upper nappe trajectory and throw distance for the maximum anticipated discharge of 800,000 cfs was also determined from the model.

FOREWORD

The model investigation reported herein was authorized by the Office, Chief of Engineers, U. S. Army, on 3 January 1977, at the request of the U. S. Army Engineer District, Savannah.

The study was conducted in the Hydraulics Laboratory of the U. S. Army Engineer Waterways Experiment Station (WES), Vicksburg, Mississippi, during the period January 1977 to August 1977 under the direction of Mr. H. B. Simmons, Chief of the Hydraulics Laboratory, and Mr. J. L. Grace, Jr., Chief of the Hydraulic Structures Division, and under the general supervision of Mr. N. R. Oswalt, Chief of the Spillways and Channels Branch. The engineer in immediate charge of the model was Mr. B. P. Fletcher, assisted by Mr. B. E. Perkins. This report was prepared by Mr. Fletcher.

Commanders and Directors of WES during the conduct of this investigation and the preparation and publication of this report were COL John L. Cannon, CE, and COL Nelson P. Conover, CE. Technical Director was Mr. F. R. Brown.

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CONTENTS

CONVERSION FACTORS, U. S. CUSTOMARY TO METRIC (SI)
UNITS OF MEASUREMENT

U. S. customary units of measurement used in this report can be converted to metric (SI) units as follows:

| Multiply	By	To Obtain
cubic feet per second	0.02831685	cubic metres per second
feet	0.3048	metres
foot-kips	1.355818	metre kilonewtons
inches	25.4	millimetres
kips (force)	4.448222	kilonewtons
miles (U. S. statute)	1.609344	kilometres
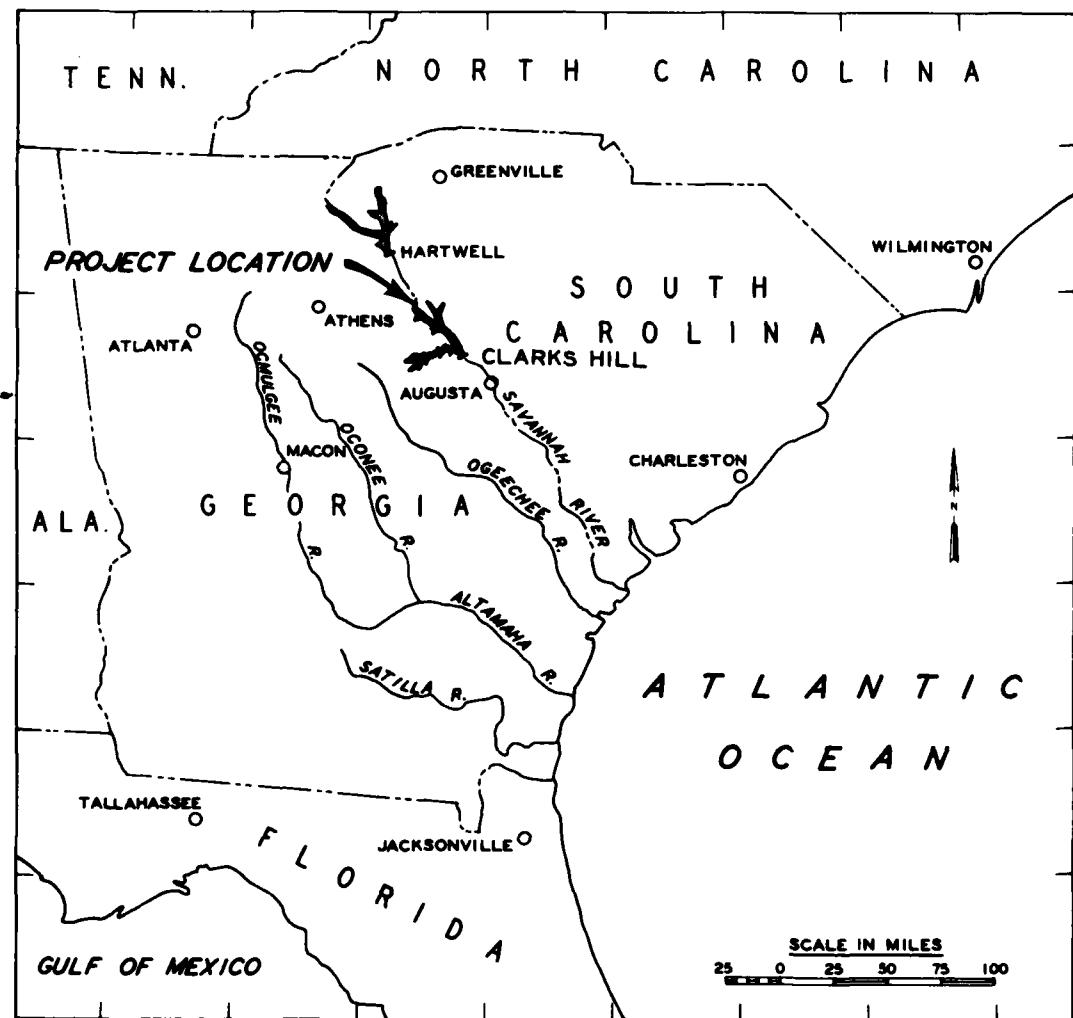
Figure 1.   Vicinity map

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SIDEWALL FORCES ON RICHARD B. RUSSELL
FLIP BUCKET SPILLWAY, SAVANNAH RIVER

Hydraulic Model Investigation

PART I: INTRODUCTION

The Prototype

1. The Richard B. Russell damsite (Figure 1) is located on the
Savannah River, about 16 miles* southeast of Elberton, Georgia, 29.9
miles below Hartwell Dam, and 37.4 miles above the Clarks Hill Dam. The
dam will have a total length of about 6,000 ft and a top elevation of
498** and will include a 600-MW powerhouse and a 590-ft-long concrete
spillway. The spillway will have a crest elevation of 436 and a net
length of 500 ft. Energy dissipation will be provided by a flip bucket.
A concrete wall will be located between the powerhouse tailrace and flip
bucket to reduce lateral flow.

2. Results of model studies conducted by the U. S. Army Engineer
Waterways Experiment Station to evaluate energy dissipation by a flip
bucket and a stilling basin were reported by Fletcher and Grace (1973).†
Results of these tests indicated that the stilling basin provided the
best energy dissipation; however, due to economic reasons, the flip
bucket was selected for the proposed project.

Purpose of Investigation

3. The model investigation was primarily concerned with providing

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* A table of factors for converting U. S. customary units of measure-
  ment to metric (SI) units is presented on page 3.
** Elevations (el) cited herein are in feet referred to mean sea level.
† B. P. Fletcher and J. L. Grace, Jr. 1973 (Jun). "Model Study of
  Trotters Shoals Spillway; Hydraulic Model Investigation," Technical
  Report H-73-7, U. S. Army Engineer Waterways Experiment Station, CE,
  Vicksburg, Miss.

design information relative to the magnitude, frequency, and location of the resultant dynamic loading acting on the flip bucket sidewall located between the powerhouse and spillway for various discharges. Tests were also conducted to determine the upper nappe trajectory for the maximum anticipated spillway discharge and the minimum height of flip bucket sidewall required.

PART II: THE MODEL

Description

4. The model was originally constructed to an undistorted linear scale of 1:80 reproducing all topography and structures in an area extending 2,000 ft upstream and 2,000 ft downstream from the axis of the dam (Figures 2 and 3) for study of the spillway and energy dissipator.

5. The apparatus used to measure the magnitude and frequency of the forces acting on the individual monoliths is shown in Figures 4 and 5. The upstream edge of the first machined aluminum monolith was located at the point of curvature of the flip bucket and the downstream edge was located 81.0 ft downstream at the end of the flip bucket. The second monolith extended from the downstream end of the flip bucket to the downstream end of the powerhouse, a distance of 70 ft. The third monolith extended from the downstream end of the powerhouse to a point
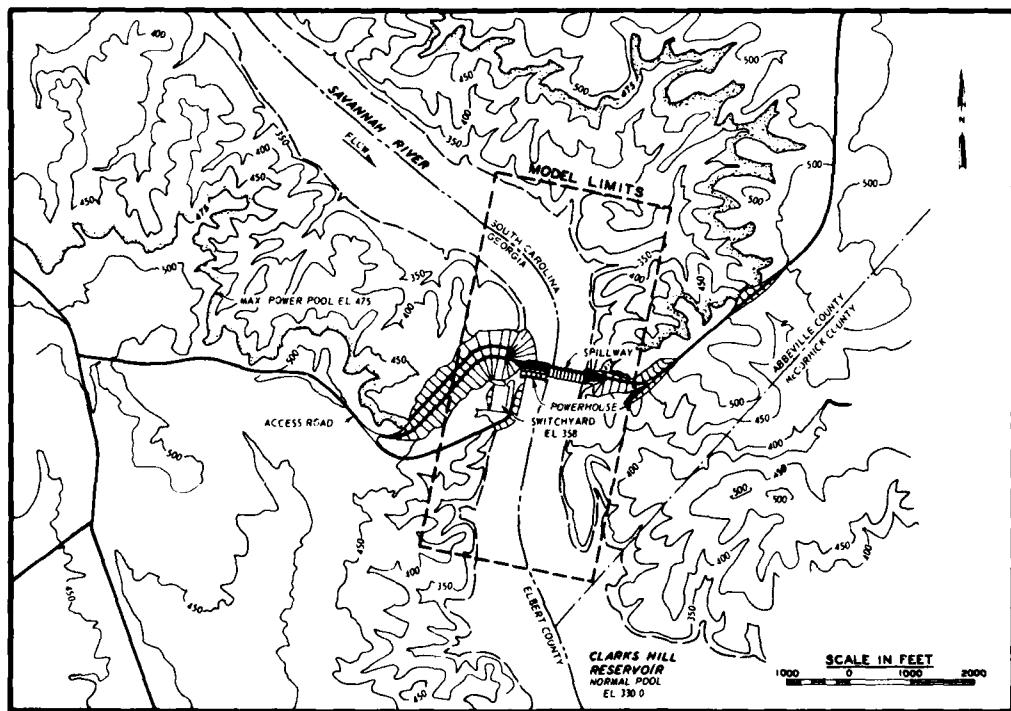
Figure 2. General plan of project, original design

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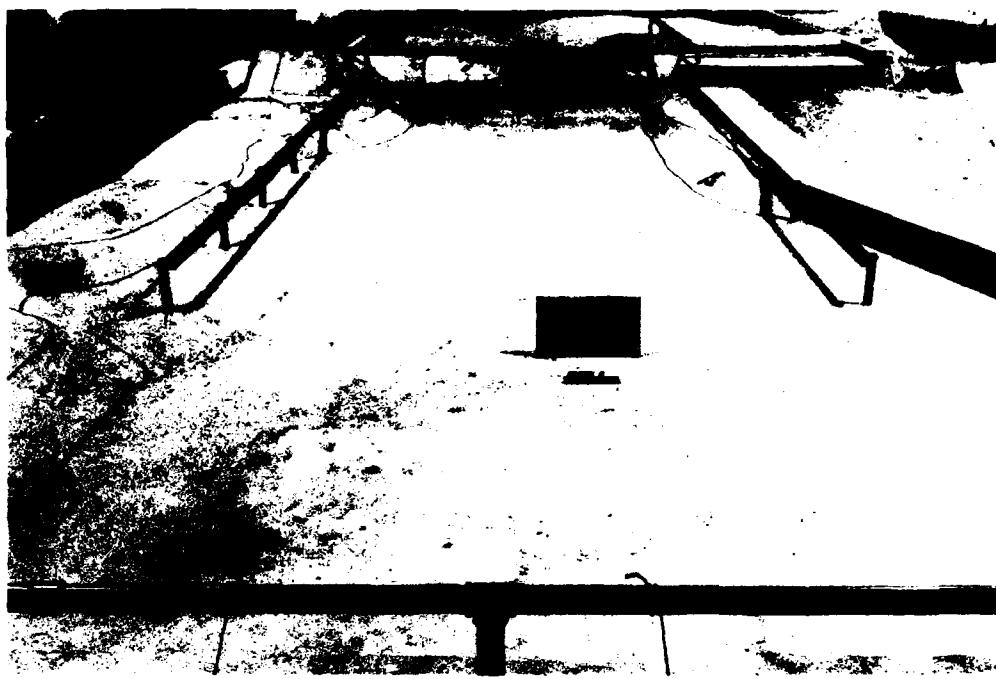
a. Looking upstream

b. Looking downstream

Figure 3. General views of the 1:80-scale model of Richard B. Russell
spillway (Trotters Shoals - original design)
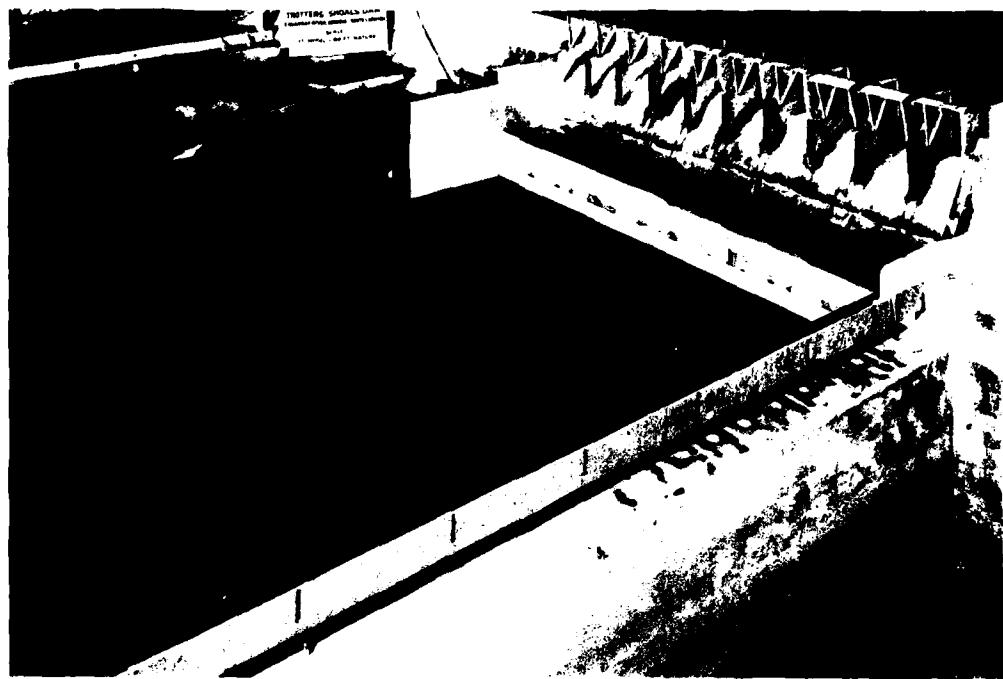
a. Front side

b. Back side

Figure 4. Flip bucket sidewall

PROFILE - D/S END OF WALL

SECTION A-A
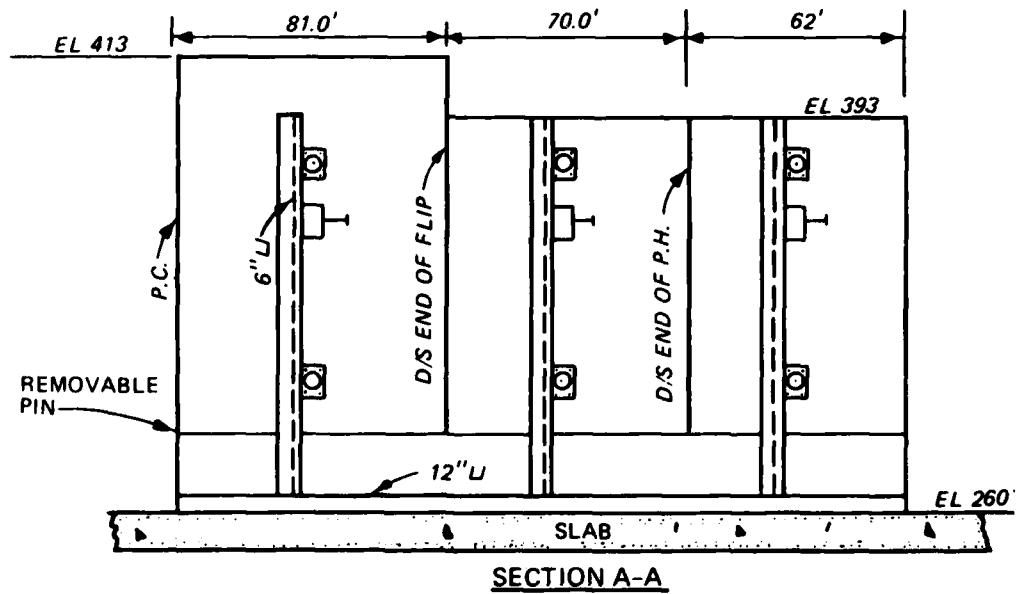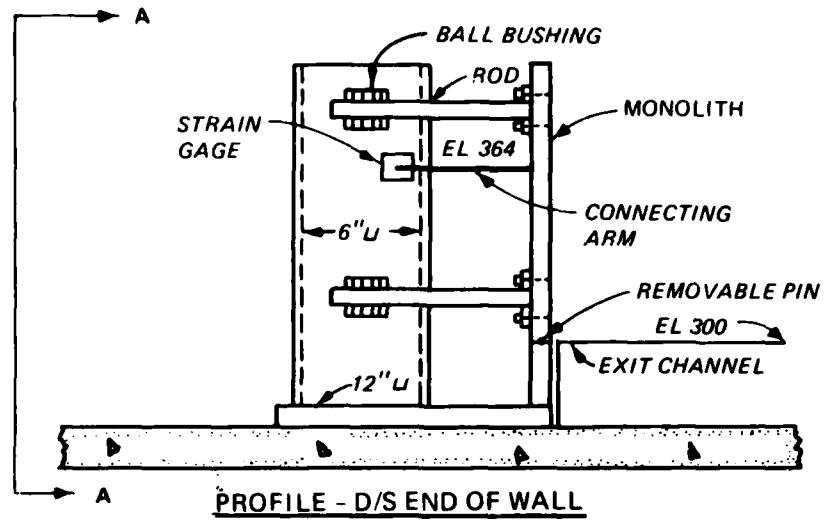
NOTE: EACH MONOLITH INDIVIDUALLY
      SUPPORTED AND 0.003 FT (MODEL)
      DISTANCE BETWEEN MONOLITHS.

Figure 5. Schematic of flip bucket sidewall

located 62 ft downstream. The tops of the monoliths were located suffi-
ciently high to contain the nappe resulting with the design discharge
of 800,000 cfs.

6. Water used in the operation of the model was supplied by pumps,
discharges were measured by venturi meters, and the magnitude and fre-
quency of the dynamic forces were measured by strain gages mounted as
shown in Figure 5. Steel rails set to grade along the sides of the
flume provided reference planes for measuring devices. Water-surface
elevations were measured by means of point gages.

Interpretation of Model Results

7. The accepted equations of hydraulic similitude, based on the
Froudian criteria, were used to express the mathematical relations be-
tween the dimensions and hydraulic quantities of the model and prototype.
The general relations expressed in terms of the model scale or length
ratio L_r are presented in the following tabulation:

Dimension	Ratio	Scale Relation
Length	L_r	1:80
Area	$A_r = L_r^2$	1:6,400
Velocity	$V_r = L_r^{1/2}$	1:8.94
Discharge	$Q_r = L_r^{5/2}$	1:57,243
Time	$T_r = L_r^{1/2}$	1:8.94
Force	$F_r = L_r^3$	1:512,000
Frequency	$f_r = 1/L_r^{1/2}$	1:0.11

8. Measurement of each of the dimensions or variables can be
transferred quantitatively from model to prototype equivalents by means
of the above scale relations.

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PART III: TESTS AND RESULTS

Height of Flip Bucket Sidewall

9. Tests were conducted to determine the minimum height of flip
bucket sidewall required downstream from the powerhouse. The top of
the downstream monolith was lowered from el 393 to 356 (maximum tailwater
elevation) as shown in Figure 6. Tests conducted with the maximum dis-
charge of 800,000 cfs and a tailwater elevation of 356 indicated no
change in the hydraulic characteristics. The top of the downstream
monolith was lowered to el 346, and a significant amount of lateral flow
passed over the top of the wall. This lateral flow contributed to in-
creased current velocities in the eddy along the right side of the exit
channel, increased confinement of flow from the flip bucket along the
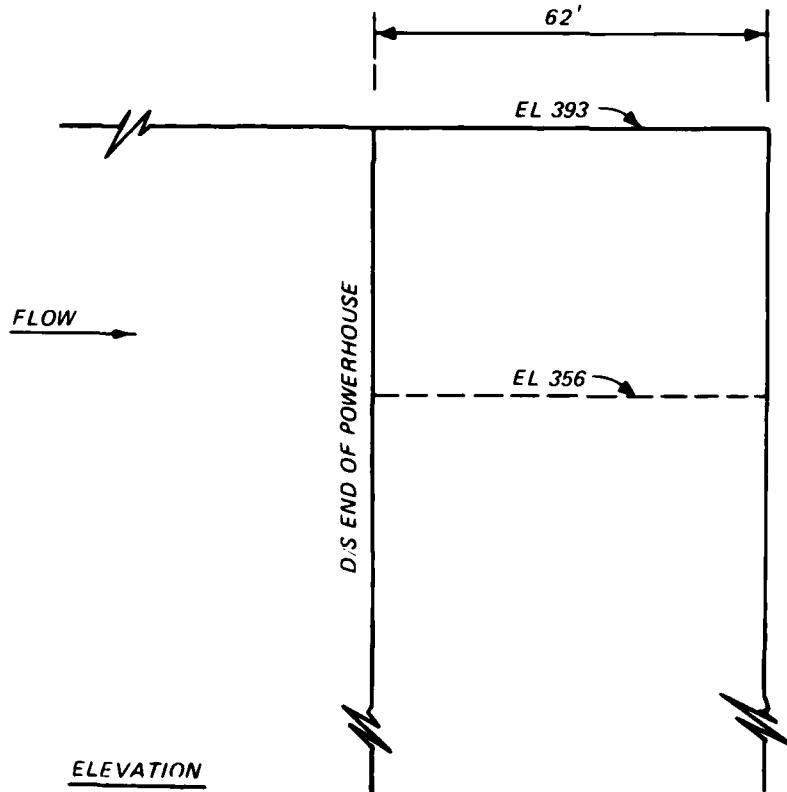
Figure 6. Downstream monolith, flip bucket sidewall

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left side of the exit channel, and increased lateral flow entrainment with flow from the flip bucket. Based on the above ovservations it was recommended that the top of the downstream monolith be located at el 356.

Forces Acting on Sidewall

10. Each monolith was mounted to permit measurement by strain gages of the resultant forces normal to the longitudinal center line of the stilling basin and the overturning movement about the base of each monolith. The resultant forces were measured when the pin at the base of the monolith was removed (Figure 5). This permitted the monoliths to be supported in the vertical plane by the ball bushings and allowed measurement of the magnitude and frequency of the resultant forces in the horizontal plane by the strain gages. Each monolith was equipped with a strain gage, which had a maximum deflection of 0.001 in., to measure the dynamic forces induced by the turbulent jet exiting the spillway. Overturning moments were determined by inserting the pin and disconnecting the rods. The pin connections permitted rotation of the monoliths about their base (el 300), and the strain gages detected the magnitude and frequency of the forces at a position 64 ft above the base of the monoliths.

11. Initially, tests were conducted to determine if the natural frequency or damping of the system would influence measurement of the forces. Results of these tests revealed that the exciting forces occurred at a predominant frequency of about 0.10 Hz (prototype) and the natural frequency of the system (3.9 Hz, prototype) was too high to influence the force measurements through resonance effects. Several tests were conducted with and without the wall immersed in water. There was no discernible damping of the forces due to the mechanical system or the hydrostatic load on the monoliths.

12. Tests were conducted to determine the forces on the sidewall for the following hydraulic conditions:

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Maximum Probable Flood	Standard Project Flood
Discharge 800,000 cfs	Discharge 360,000 cfs
Pool el 490	Pool el 469
Tailwater el 356	Tailwater el 343

Figures 7 and 8 illustrate the hydraulic conditions investigated. Forces detected by the strain gages were recorded on an oscillograph chart as indicated by a typical record (Figure 9).

13. The data obtained were analyzed and the magnitude, frequency, and overturning movement relative to the base of the wall (el 300) were computed and are shown in Table 1. Forces tending to displace the walls outward from the flip bucket are assigned a negative sign. The values listed under the columns labeled "Predominant Amplitude," "Maximum Amplitude in the Positive Direction," and "Maximum Amplitude in the Negative Direction" are equal to the displacements from the average force datum shown in Figure 9. Thus, predominant and maximum magnitudes of the resultant force or shear on the monoliths can be calculated by increasing and decreasing the average force by the amplitude of forces indicated in Table 1. For example, with the discharge of 800,000 cfs, an average shear force of -940 kips (Table 1) and a predominant amplitude of force in the negative and positive directions of 240 kips with a frequency of 0.10 cps would result in a predominant negative dynamic force ranging from -700 to -1180 kips occurring periodically at the rate of 0.10 cps and tending to displace the wall away from the flip bucket. An average shear force of -940 kips and randomly occurring maximum amplitudes of force in the negative and positive directions of 940 kips would result in a randomly occurring force in the negative direction ranging from 0 to -1880 kips and tending to displace the wall away from the flip bucket.

14. The maximum and minimum overturning moment about the base of each monolith is obtained by multiplying the maximum force detected, when the monoliths are pinned at the base, by the distance of 64 ft from the gage to the base of the monolith. For example, the maximum overturning moment about the base of the wall for a discharge of 800,000 cfs (-94,080 ft-kips as shown in Table 1) was obtained by multiplying the

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a. Viewed from left side of exit channel
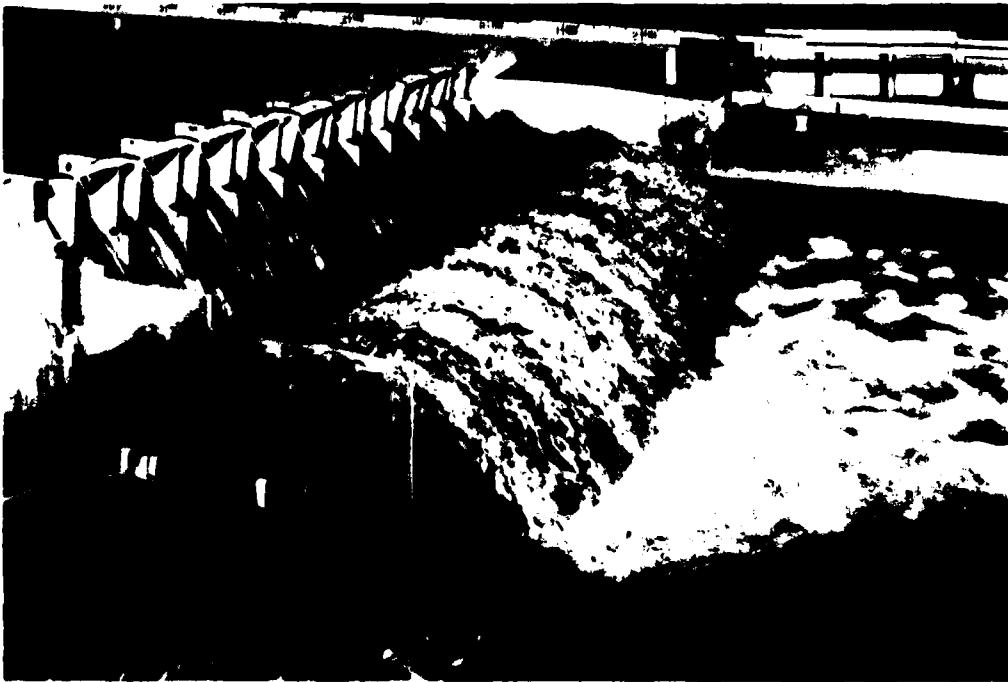
b. Viewed from right side of exit channel

Figure 7. Flow conditions; discharge 360,000 cfs, pool el 469,
tailwater el 343
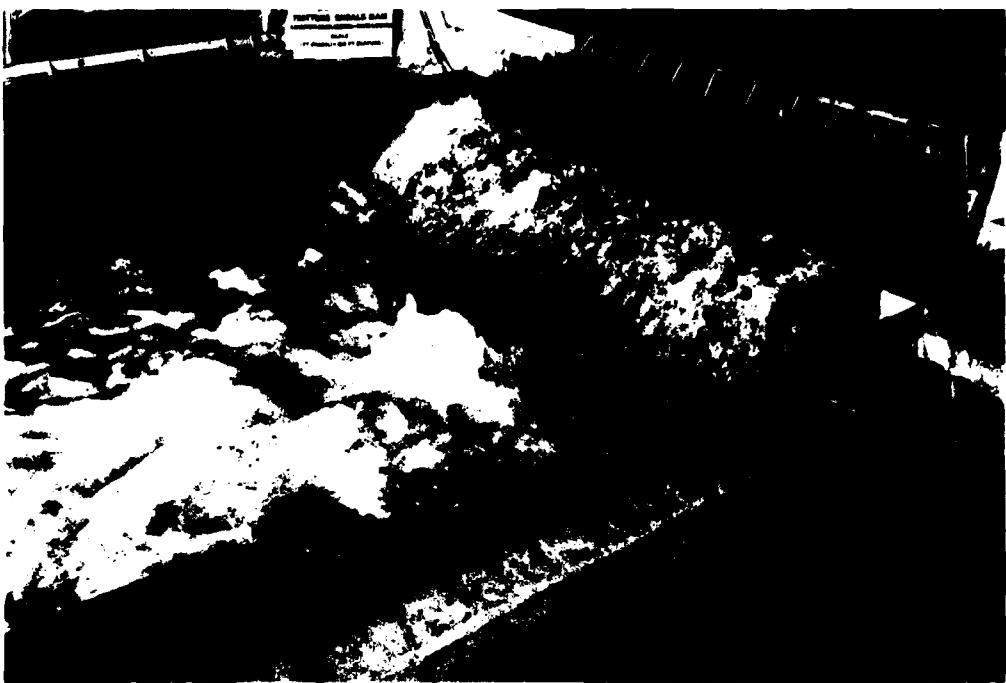
a. Viewed from left side of exit channel
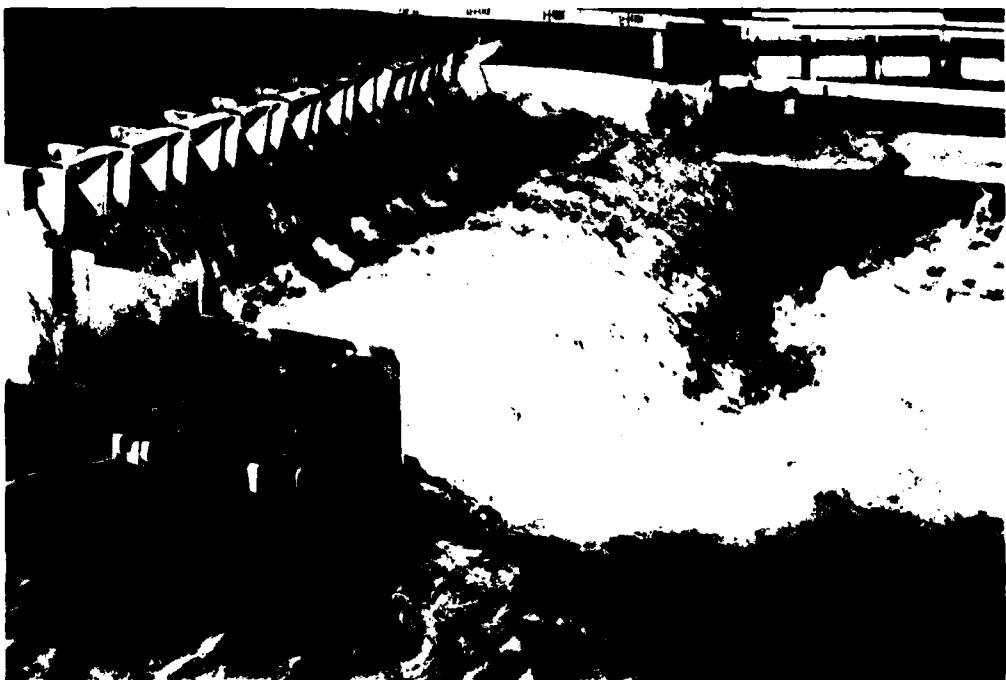
b. Viewed from right side of exit channel

Figure 8. Flow conditions; discharge 800,000 cfs, pool el 490,
tailwater el 356
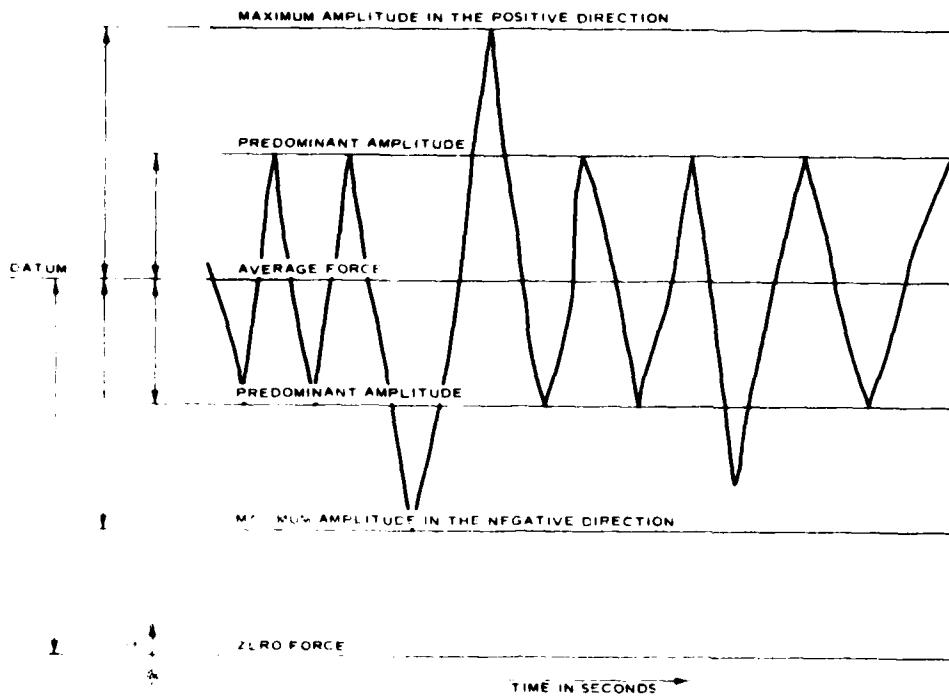
Figure 9. Typical trace produced on oscillograph chart

average force (-870 kips) plus the maximum amplitude of force in the negative direction (-600 kips) by the distance from the strain gage to the base of the monolith (64 ft). The minimum overturning moment for this same discharge and monolith (-17,280 ft-kips) was obtained by multiplying the average force (-870 kips) minus the maximum amplitude of force in the plus direction (600 kips) by the distance from the strain gage to the base of the monolith (64 ft). The approximate length of the moment arm (50 ft) from the base of the monolith to the point of the maximum resultant load was obtained by dividing the maximum overturning moment about the base of the monolith (-94,080 ft-kips) by the sum of the average shear force (-940 kips) and maximum amplitude of shear force in the negative direction (-940 kips).

Upper Nappe Trajectory

15. Tests were conducted to determine the flip bucket upper nappe trajectory and throw distance from the maximum anticipated discharge of

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800,000 cfs. Figure 10 presents a plot of the upper nappe trajectory
and the basic data obtained from the model. The model nappe was not
enlarged significantly, as it would be in the prototype, due to air
entrainment.

| DISTANCE FROM LIP, FT	ELEVATION, FT MSL
-35	365
0	380
33	385
60	397
88	404
120	404
150	393
200	377
275	305
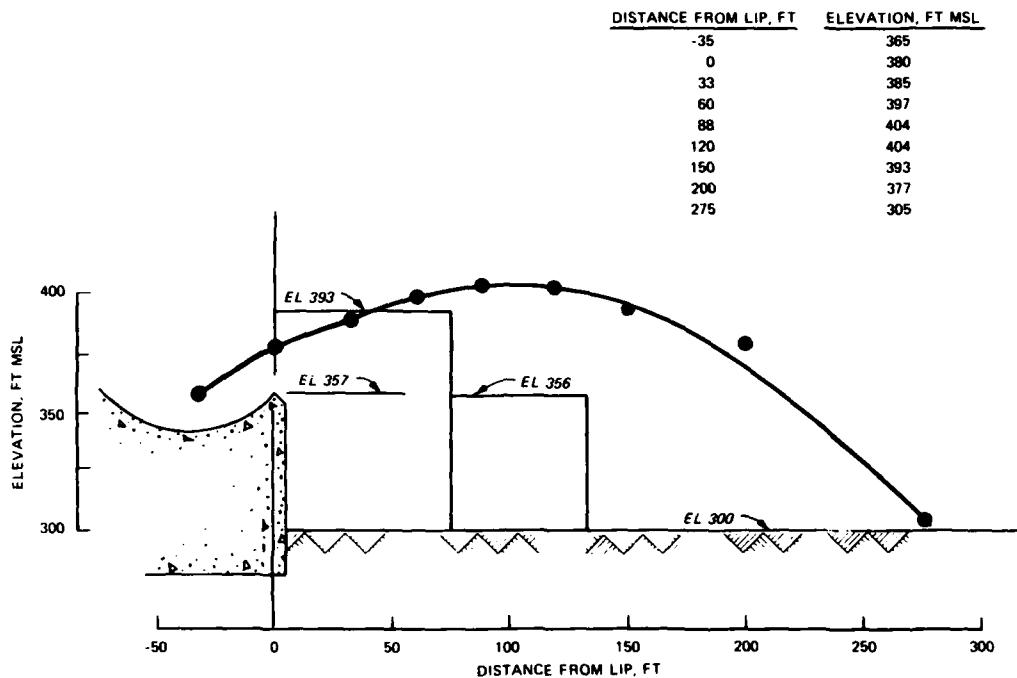
Figure 10. Upper nappe trajectory, discharge 800,000 cfs

16. Theoretical computations of the maximum values of the upper
nappe trajectory height and throw distance to be expected with the full
range of heads and discharges indicate the following:

Discharge cfs	Head ft	x ft	y ft
33,000	127.7	291	49.3
800,000	147.7	331	59.3

where the head, throw distance (x), and trajectory height (y) all are
measured from the lip of the 45-deg flip bucket. The model indicated
values about 80 to 85 percent of the theoretical values.

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PART IV: SUMMARY

17. Hydraulic model investigations indicated that the resultant dynamic forces acting on the sidewall resulted from the combination of turbulence on the flip bucket side of the wall and hydrostatic pressure on the powerhouse side of the wall.

18. It was possible to lower the top of the downstream portion of the sidewall from el 393 to el 356 without return flow passing over the top of the wall. With the top of this wall lower than el 356, return flow over the top of the sidewall contributed to adverse flow conditions including increased current velocities in the powerhouse tailrace, confinement of flow along the left side of the exit channel, and lateral flow entrainment with flow from the flip bucket.

19. Tests conducted, with and without the wall immersed in water, to investigate the natural frequency and damping of the model wall indicated that the natural frequency of the model wall was too high to influence the results of the tests and there was no discernible damping of the forces due to the mechanical system. Forces on the sidewall were measured for the standard project flood (discharge 360,000 cfs) and the maximum probable flood (discharge 800,000 cfs). The data obtained were analyzed, and the magnitude and frequency of the resultant force and overturning moment relative to the base of the wall (el 300) were computed and tabulated.

20. The upper nappe trajectory and throw distance for the maximum anticipated discharge of 800,000 cfs, as determined from the model, were about 85 percent of the theoretical values.

Table 1

Amplitude and Frequency of Forces Acting on Flip Bucket Sidewall Monoliths

Type Force	Discharge cfs	Pool Elevation ft msl	Tailwater Elevation ft msl	Monolith No.	Average Force* kips	Predominant Frequency cps	Predominant Amplitude kips	Maximum Amplitude + Direction kips	Maximum Amplitude - Direction kips	Maximum Overturning Moment About Base of Wall* (el -300) ft-kips
Moment	360,000	469	343	1	-270	0.10	75	300	300	-36,480
				2	210		35	140	140	22,400
				3	200		43	170	170	23,680
Shear				1	-430		125	500	500	
				2	420		88	350	350	
				3	410		80	320	320	
Moment	800,000	490	356	1	-870		150	600	600	-94,080
				2	140		68	270	270	26,240
				3	140		68	270	270	26,240
Shear				1	-940		240	940	940	
				2	770		120	490	490	
				3	810		140	540	540	

* - Indicates force is acting away from flip bucket.

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